



Soil Health Planning Principles “a practical approach to Farming in the 21st Century”

Presentation prepared by the USDA-NRCS
National Soil Health and Sustainability Team
(modified from the original to accommodate notes with photos)

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New Mexico Integrated Cropping Systems and Water Management Handbook
http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nm/technical/?cid=nrcs144p2_068965

USDA-NRCS: Unlock the Secrets in the Soil
<http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/>

Soil Health What is It?



- The continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans
 - Nutrient cycling
 - Water (infiltration & availability)
 - Filtering and Buffering
 - Physical Stability and Support
 - Habitat for Biodiversity

This is the **definition of Soil health** we are using. The term “Health” was purposely chosen instead of “quality”.

- **Quality implies** analysis and quantifying
- **Health implies** management actions that leads to a condition or state, there is something that can be done to change it in a positive trend

The key to the definition is that **soil health is:**

1. **Continued capacity**—implies rejuvenation and then sustainability.
2. **Soil is a living ecosystem**— most folks don’t think of the ground beneath them a living ecosystem.
3. **Soil function** – soils need to provide the basic functions below in order for food & fiber production to be successful/sustainable.
 - a) **Nutrient Cycling** - Soil stores, moderates the release of, and cycles nutrients and other elements. During these biogeochemical processes, analogous to the water cycle, nutrients can be transformed into plant available forms, held in the soil, or even lost to air or water.
 - b) **Water Relations** - Soil can regulate the drainage, flow and storage of water and solutes, which includes nitrogen, phosphorus, pesticides, and other nutrients and compounds dissolved in the water. With proper functioning, soil partitions water for groundwater recharge and for use by plants and soil animals.
 - c) **Biodiversity and Habitat** - Soil supports the growth of a variety of plants, animals, and soil microorganisms, usually by providing a diverse physical, chemical, and biological habitat.
 - d) **Filtering and Buffering** - Soil acts as a filter to protect the quality of water, air, and other resources. Toxic compounds or excess nutrients can be degraded or otherwise made unavailable to plants and animals.
 - e) **Physical Stability and Support** - Soil has the ability to maintain its porous structure to allow passage of air and water, withstand erosive forces, and provide a medium for plant roots. Soils also provide anchoring support for human structures and protect archeological treasures.



Soil Health Planning Principles

- Manage more by Disturbing Soil Less
- Use Diversity of Plants to add diversity to
Soil Micro-organisms
- Grow Living Roots Throughout the year
- Keep the Soil Covered as Much as Possible

Goal: To create the most favorable habitat
possible for the soil food web



Manage More by Disturbing Soil Less

- **Agricultural Disturbance Destroys
Dynamic Soil Properties**
- **Destroy “Habitat” for Soil Organisms**
- **Creates a “Hostile” Environment**
- **Three Types of Disturbance**
 - **Physical (tillage)**
 - **Chemical (Fertilizer)**
 - **Biological (overgrazing)**

Dynamic soil proprieties are those that can be influenced by human activities Include:

Soil Organic Matter

Structure

Infiltration rate

nutrient and water holding capacity & availability

Soil is Habitat that provides **Food, Water & Shelter** for organisms to live.

Agricultural disturbance destroys habitat in which beneficial organisms could thrive and creates habitat that non-beneficial organisms can tolerate or thrive in.

All three types of disturbance end in degraded soils.

What things change when you stop tilling the soil?



- Soil pores remain continuous
- Soil aggregates form and are not destroyed
- Soil Food Web increases and diversifies
- Weed seeds are not planted
- Water is captured and stored
- Bulk density increases slightly; then stabilizes
- Soil fungi and earthworms increase
- Microarthropods increase (>20% of nutrient cycle)

Here are positive changes in the soil that occur when you stop tillage:

- **Pores** remain continuous-allows for increased infiltration
- **Aggregates form** – increase soil stability, improves aeration and provides habitat for soil microbes
- **SFW** – adds trophic levels and complexity, increasing functional groups
- **Water** is held in place by increased SOM and held until plants require it
- **Bulk density** decrease over time to levels that approach native conditions
- **Soil organisms** flourish because their habitat is not being destroyed

Human nature drives us to tillage!



- We enjoy power!
- Feel in control!
- We can see what we accomplished!

Human's relate hard physical work with success.



Hard to believe that the same results can be achieved using simpler biological methods!!!



- The challenge to soil health is to convince farmers that they can achieve many of the same results they are seeking when they till by **using biological methods**.
- Photos are of **tillage radish** planted in a timely fashion that allows it to growing into the soil profile greater than 12", notice the soil line.
- The photo in the bottom right shows tillage radishes planted using a split row planter ever 4". You can see the **"bio-drilling"** that is being achieved, compares to the results that you can get with an inline ripper without the added cost of diesel fuel.
- In addition the **tillage radish** **scavenge excess N**, **pull up P** from deep in the soil profile and provide some nematode control as an added bonus.



Healthy Soils are forgiving soils



Here's an example system in which the producer has maximized not disturbing the soil:

- **Cover crops** is a mix of cereal rye, crimson clover and hairy vetch
- Using a Brillion **cultipacker** that he had used previously to knockdown cotton stalks, to roll this 6 foot tall cover down
- He is spraying as he rolls
- Lower left picture shows **rolling and planting** at the same time
- Lower right picture shows how forgiving healthy soils are: **good soil moisture, well aggregated**, no trouble to get seed in the ground and covered.

Soil Health Principle 2

Use Diversity of Plants to add diversity to Soil Organisms



- Plants interact with particular microbes
 - Trade sugar from roots for nutrients
- Microbes convert plant material to OM
- Requires a diversity of plant carbohydrates to support the variety of microbes
- Lack of plant diversity will drive system to favor some microbes more than others

- **Plants exudates** attract a particular variety of soil microbes.
- **Microbes use these exudates** to do the various function that support plant growth, e.g. decompose organic matter, cycle nutrients, enhance soil structure, and control populations of soil organisms including pest.
- **The more plant exudates in the soil the wider variety of soil organisms** that the soil can support, adds complexity and resilience.
- **Lack of diversity** reduces the number and types of organism that can thrive, soils are less complex and lack resilience.
- “Supersize Me”: The movie is about a man that ate McDonalds food every meal for a month, **the lack of diversity in his diet cause his blood work to get out of balance**, he gained weight and his general health went down. His doctor’s pleaded with him to get off the diet. This is the same principle as feeding the soil corn exudates every year and the effect it has on the soil organisms.

Impact of Biodiversity



- Lack severely limits any cropping system
- A diverse and fully functioning system provides nutrients, energy and water
- **Diversity above ground equals diversity below ground**



What impact does increasing biodiversity have on a cropping system?

- Lack of biodiversity limits the cropping system, How?? Disrupts how soils function, less nutrient cycling, water infiltration, increase pest (weeds & diseases), etc.
- A diverse and fully functioning soil ecosystem means that:
 - All the organisms that plants require are present and functioning
 - Nutrients in the soil are in the proper form for plants to take up
 - Nutrients are being held in the soil in non-leachable forms
 - Correct ratio of soil organisms are present
 - Fungi to bacteria
 - Predator to prey
 - When this occurs the system provides the energy, nutrients and water to produce crops
- Diversity in plant community above ground equals or indicates a diverse soil biota

How to Increase Diversity in a Crop Rotation



- **Lengthen the rotation by adding more crops**
 - **Increases soil organic matter**
 - **Breaks pest cycles**
 - **Improves nutrient utilization and availability**
 - **Utilize available water deeper in the soil profile**
 - **Provide windows for management**
 - **spread manure**
 - **Plant & harvest crops**
- **Add more plants in the current crop rotation**
 - **Utilize cover crops during non-cropping part of the year**

There are 2 basic ways to add plant diversity to a crop rotation:

1. Lengthen the current rotation by adding more crops, e.g. corn-bean rotation goes to corn-beans-wheat

1. Benefits include:

- Increase the amount of biomass produced can increase SOM
- Planting difference crops breaks pest and weed cycles
- Planting a variety of shallow and deep rooted crops utilizes soil moisture and nutrients
- Provides windows of opportunity to spread manure in more suitable time of the year, plant and harvest crops with out conflict, etc.

2. Add more plants in the current rotation

1. Utilize the non-cropping portion of the year to grow cover crops
2. Be sure to use multi-species cover crops when possible

Cover Crop Role in Diversity

1. Allow you to look at cropping periods rather than years
2. Can be used to accelerate rejuvenating soil health
3. Getting 6 to 8 weeks of growth is adequate to get some of the “rotation” effect benefits!
4. Will increase soil biological diversity

“Diversity above = diversity below”

Cover crops and multi-species cover crops play a big role in adding diversity into a cropping system

- Farmers are hesitant to add more cash crops to a rotation, cover crops allow for diversity to be inserted into periods of the year that normally would not have a living root growing and no exudates being placed into the soil
- Success of cover crops has always been judge by the amount of biomass produced above ground, **we need to consider the amount of plant exudates that are feeding soil microbes for a period of time that normally would not have gotten any food.** Having roots grow for a short period of time accomplishes this.
- **Multi-species cover crops** will add to the biological diversity within the soil

Simplified Crop Classification

- **Plant morphology**
 - Broad leaf
 - Grasses
- **Plant growth habits**
 - Cool season
 - Warm season



How do you know if you have enough diversity in the rotation?

Using this simple crop classification system and make sure you have representatives from each functional group in the rotation.

Crop Classification Warm Season



Grasses

- Corn
- Millet
- Sudan
- Sudex
- Sorghum



Broadleaf

- Alfalfa
- Soybean
- Buckwheat
- Chick pea
- Cow pea
- Sunflower

Crop Classification Cool Season



- Grasses
 - Barley
 - Rye
 - Triticale
 - Wheat



- Broadleaf
 - Canola
 - Clovers
 - Mustards
 - Pea
 - Radish
 - Turnips



Mimic Native Range



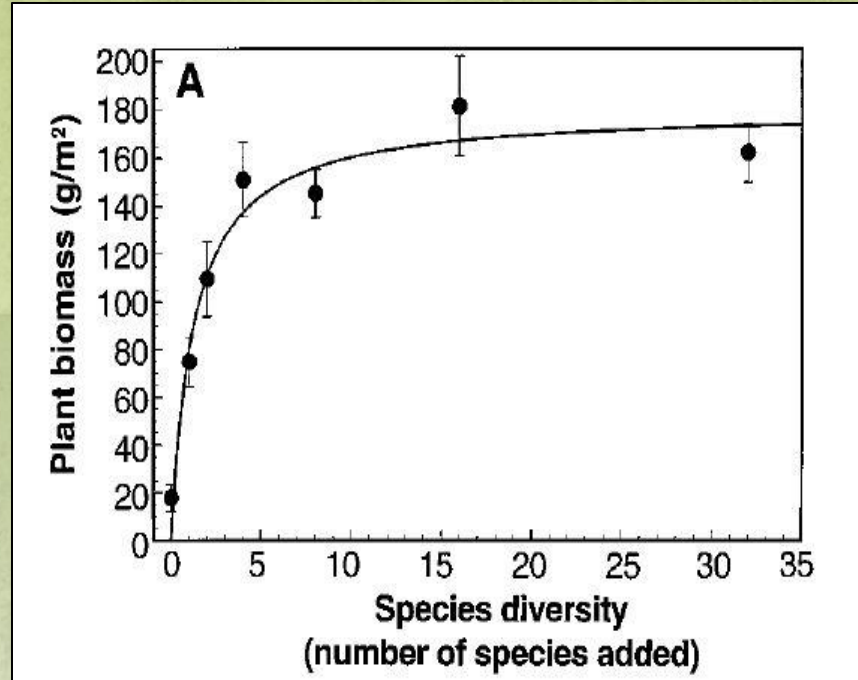
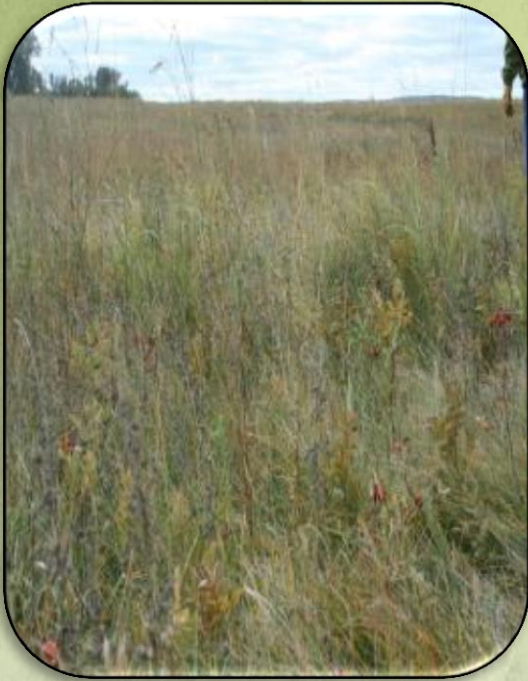
- Diversity of Plants
- Diversity of Function



What does this ecosystem contain that can be mimicked in cropping systems?

1. Diversity of plant species
2. Diversity of plant function

The Influence of Functional Diversity and Composition on Ecosystem Processes



David Tilman, Johannes Knops, David Wedin, Peter Reich, Mark Ritchie, Evan Siemann

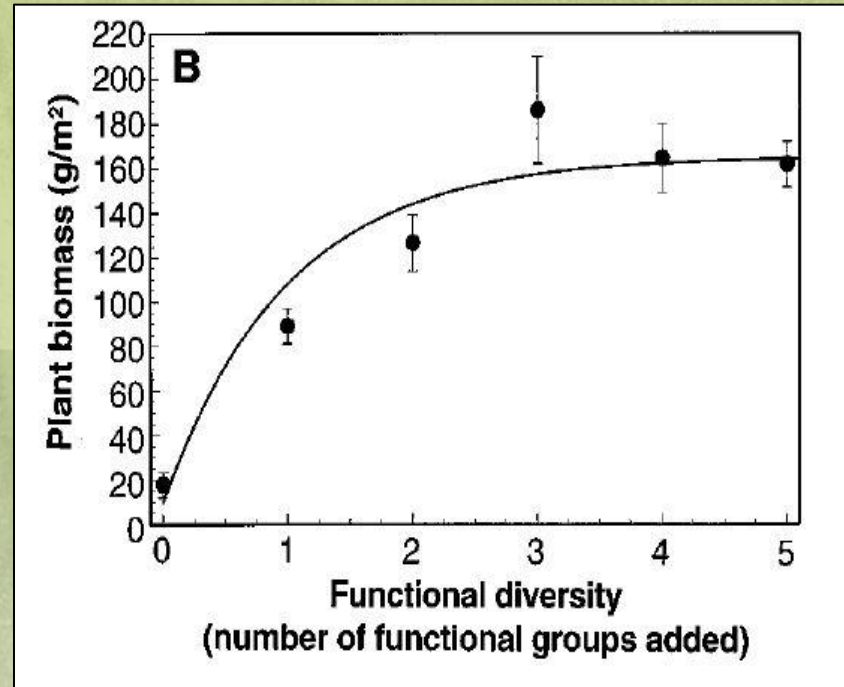
Study conducted by Dr. Tillman and others looked at influence of functional diversity and composition on Ecosystem Processes measured in Plant Biomass produced

- **Ecosystem Processes**
 - Water cycle
 - Nutrient cycle
 - Biological community
 - Energy Flow
- Species diversity defined: number of plant species added to plots
- Functional diversity defined: number of functional groups added to plots
- Functional composition defined: which functional groups were added to plots
- Functional Groups classified based on the intrinsic physiological and morphological differences, which influence differences in resource requirements, seasonality of growth, and life history

RESULTS: Measured in the amount of biomass produced not by individual ecosystem process

- **A little species diversity can have a big affect on biomass production**

The Influence of Functional Diversity and Composition on Ecosystem Processes



David Tilman, Johannes Knops, David Wedin, Peter Reich, Mark Ritchie, Evan Siemann

Results

1. **Plant composition is important in ecosystem processes**
2. **Functional diversity** has greater impact on ecosystem processes than species diversity
3. The number of functionally different roles represented in an ecosystem is a stronger determinant of ecosystem processes than the number of species
4. Factors that change ecosystem composition will have an impact on the processes, e.g. invasive plants, nitrogen use, soil disturbance, predator decimation

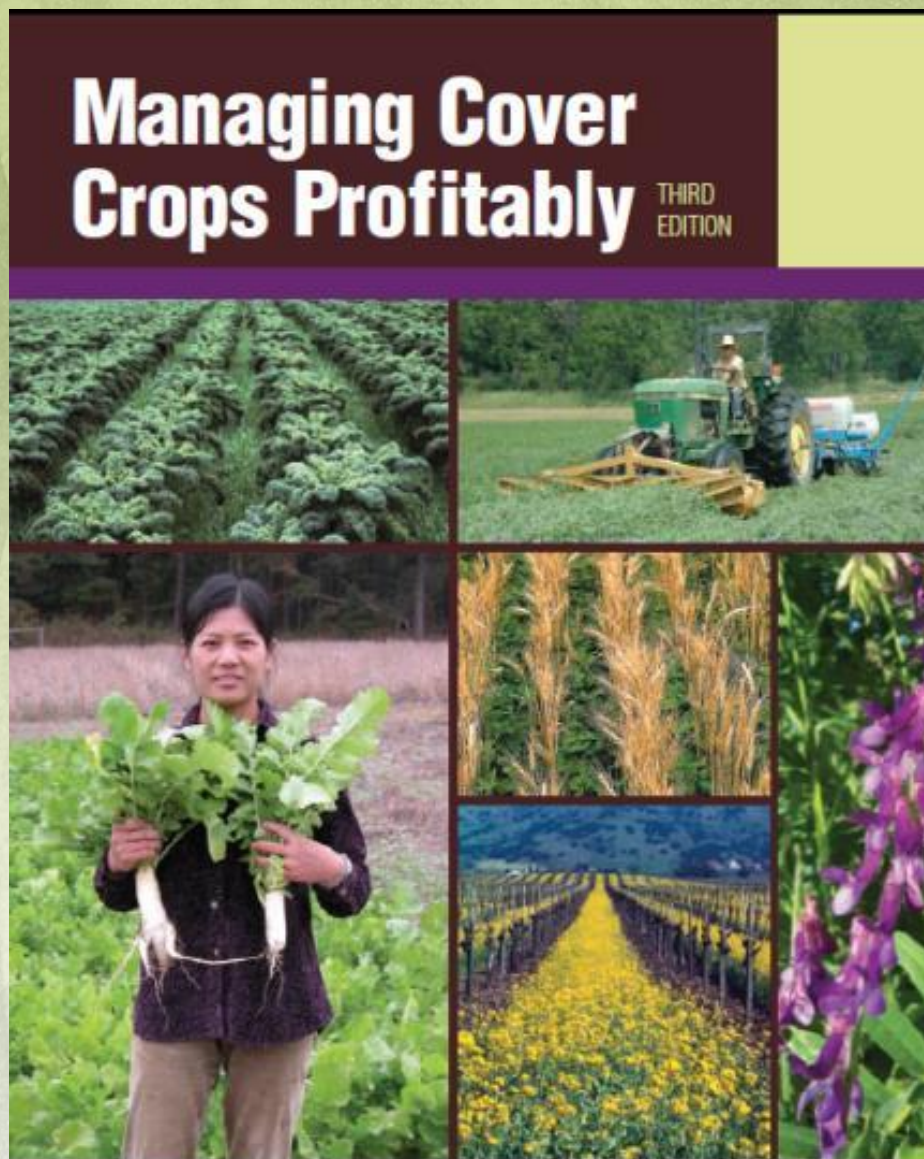
The key is that it takes more than a lot of different plant species to impact soil health; you need representation from each of the functional groups.

Results from Tillman study

Other studies have shown that the number of species (2, 6, 7, 19), the number of functional groups (8), or ecosystem species composition (20, 21) influence various ecosystem processes. Our results show that composition and diversity are significant determinants of ecosystem processes in our grasslands. Given our classification of species into functional groups, functional diversity had greater impact on ecosystem processes than did species diversity. This suggests that the number of functionally different roles represented in an ecosystem may be a stronger determinant of ecosystem processes than the total number of species, per se. However, species diversity and functional diversity are correlated; each was significant by itself, as was species diversity within functional groups; **and either species or functional diversity may provide a useful gauge of ecosystem functioning.**

Our results show a large impact of composition on ecosystem processes. This means that factors that change ecosystem composition, such as invasion by novel organisms, nitrogen deposition, disturbance frequency, fragmentation, predator decimation, species extinctions, and alternative management practices (20, 21), are likely to strongly affect ecosystem processes. **Our results demonstrate that all species are not equal.** The loss or addition of species with certain functional traits may have a great impact, and others have little impact, on a particular ecosystem process, but different processes are likely to be affected by different species and functional groups.

Cover Crop Characteristics



Good resource for information related to cover crop.
Available on line or can be purchased as a book.



Mixture of cereal rye, hairy vetch, and field peas as a winter cover crop

Mixture of cereal rye, hairy vetch and crimson clover



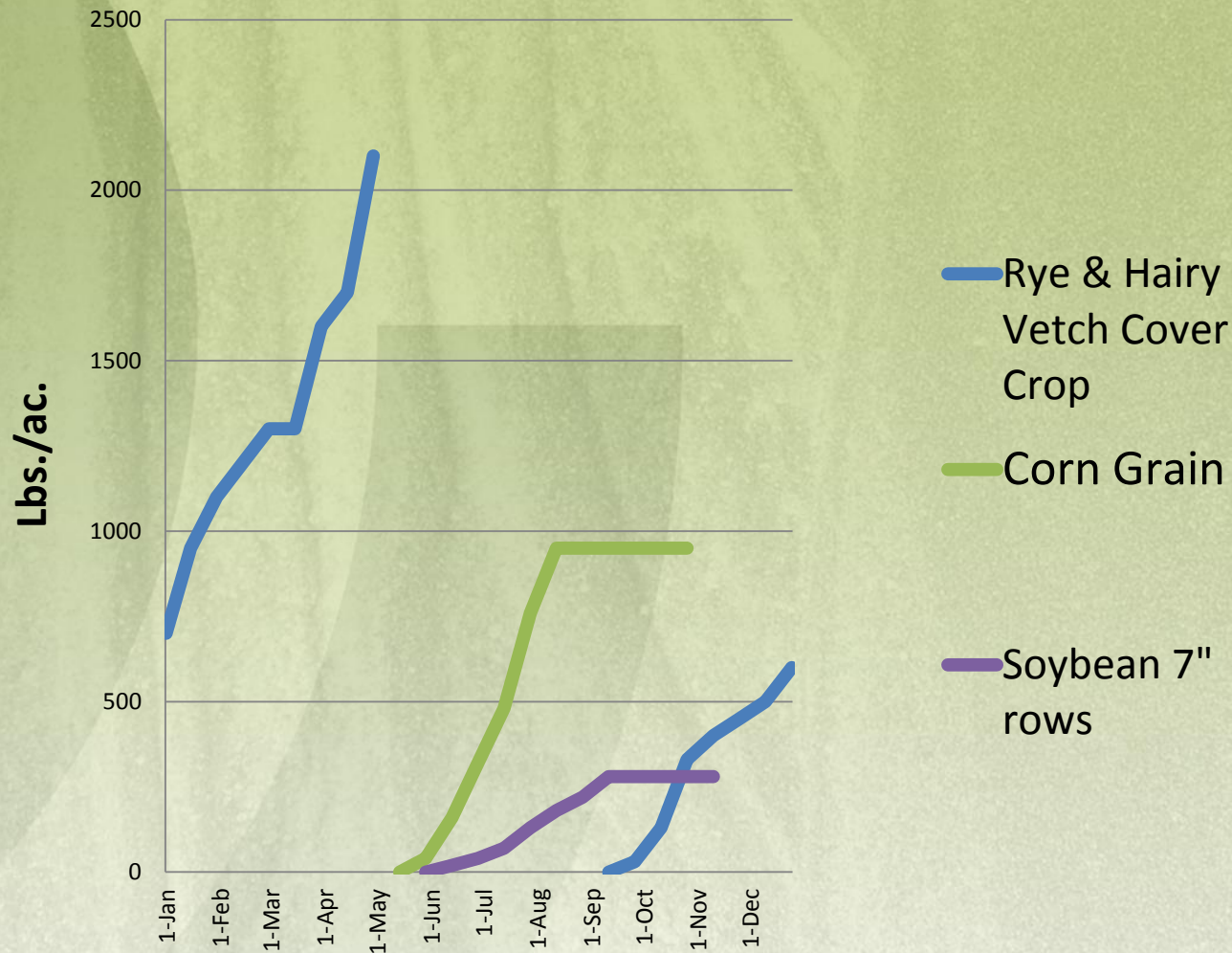
Soil Health Principle 3

Grow Living Roots Throughout the Year

Benefits:

- **Increases microbial activity that influences the N mineralization and immobilization**
- **Increases plant nutrient/vitamin uptake/ concentrations with mycorrhizal and bacteria associations**
- **Increases biodiversity and biomass of soil organisms**
- **Improves physical, chemical and biological properties of soils**
- **Sequesters and redeposit nutrients**
- **Increases OM**

Root Mass in Top 4" of Soil



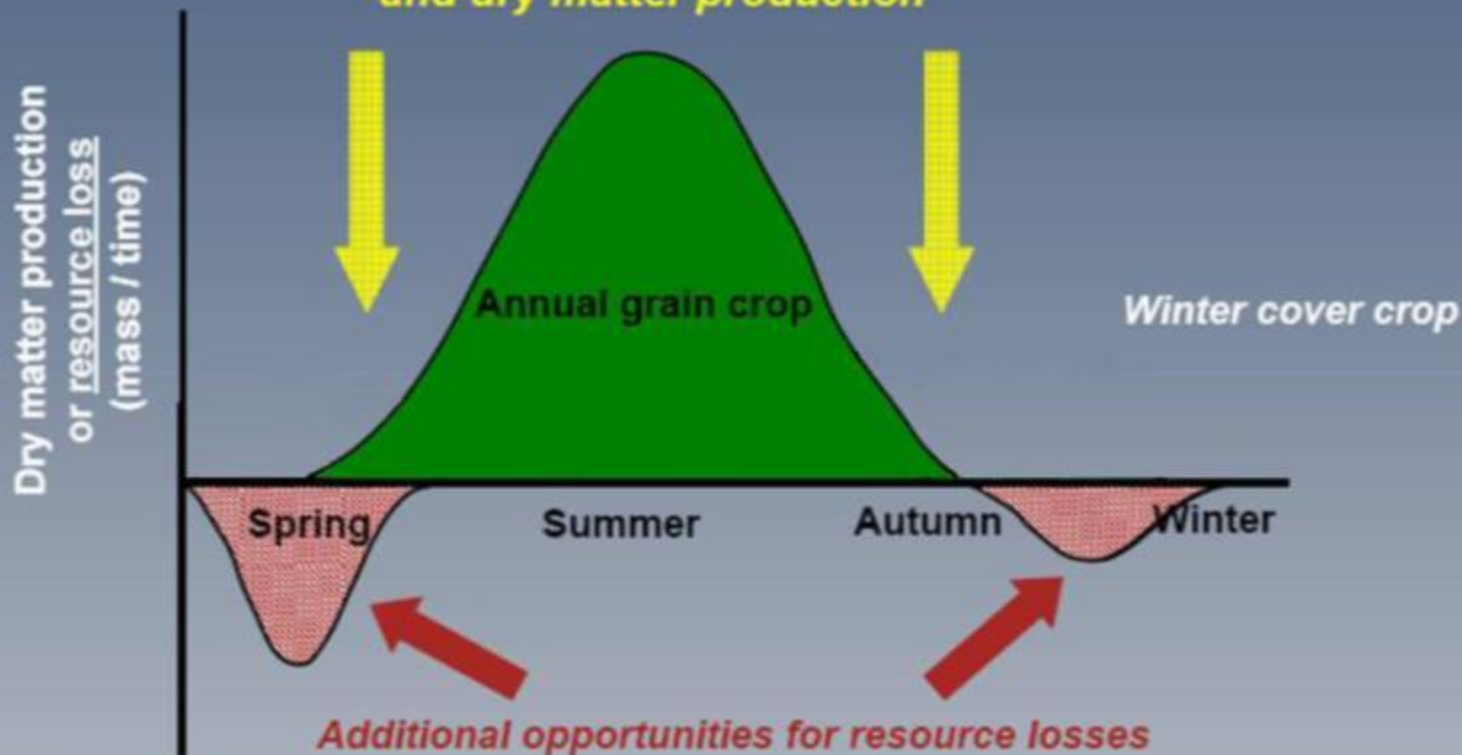
- It shows the amount of root mass produced in the top 4" for corn, soybeans and a rye & hairy vetch cover crop
- Typical corn or soybean will only grow a living root for 100 to 110 days, leaving the soil with no living root growing for the majority of the year
- **Adding a multi-species cover crop growing in the non-cropping part of the year added over 2000 lbs. of root mass providing a food source year round**

Biomass Production

Annual Cropping Systems



Missed opportunities for resource assimilation and dry matter production



after A.H. Heggenstaller

A. H. Heggenstaller, University of Alberta

Traditional cropping systems only have a living root growing 90 to 120 days of the year

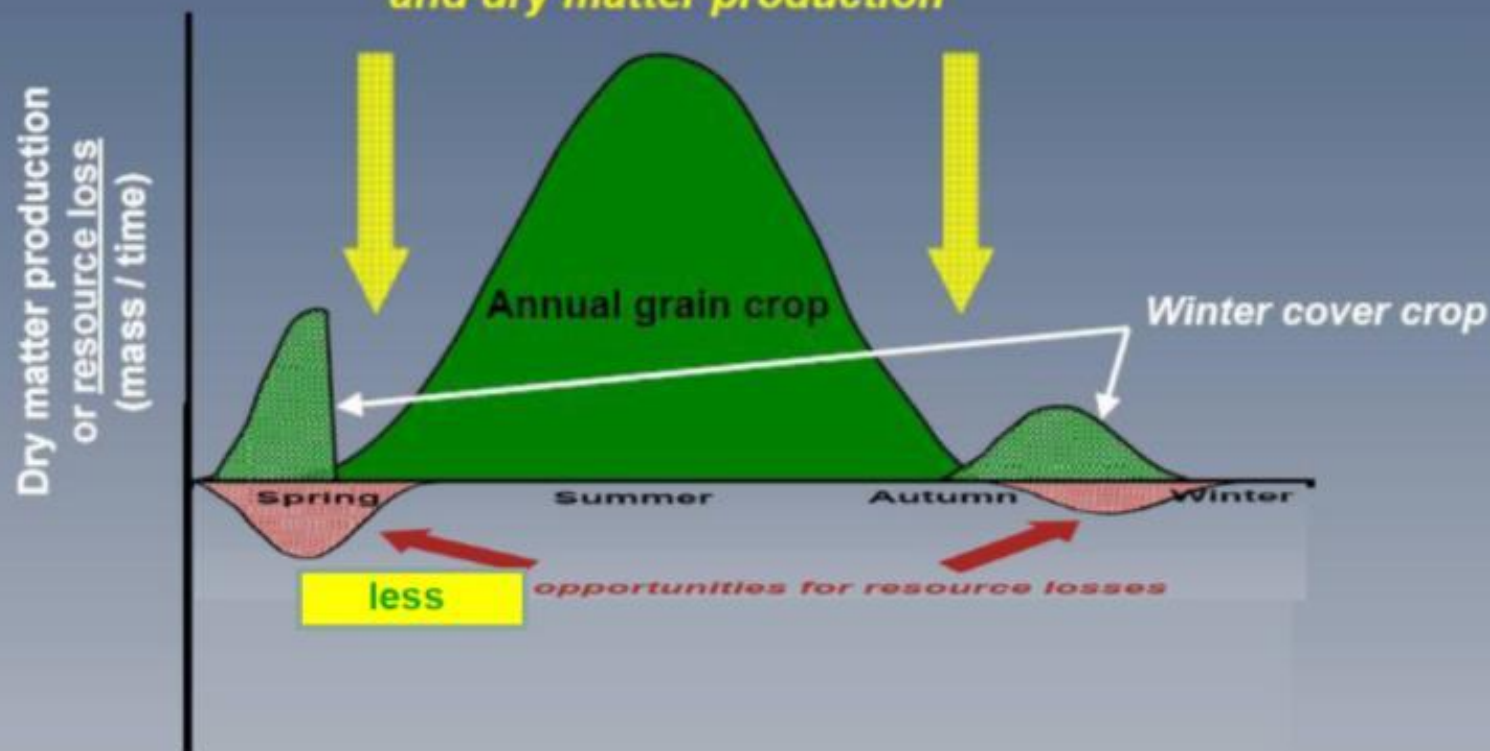
Niches exist at both ends of the growing season that provide opportunity for cover crops to be used to provide a living root

Biomass Production

Annual Cropping Systems



Cover crops for resource assimilation
and dry matter production



after A.H. Heggenstaller

A. H. Heggenstaller, University of Alberta

Cover crops can provide exudates to stimulate soil biology at both ends of the cropping season.

How to Keep a Living Root All Year Long

- **Lengthen Rotation**
 - Add Wheat
- **Select Shorter Season Varieties**
 - Choose 100 -104 day
 - Only need 6 - 8 weeks to provide benefit
- **Interseed into Growing Crops**
 - Planting cover crop before harvesting of cash crop

There are a variety of ways to get cover crops seeded in order to take advantage of a longer growing season

1. Lengthen rotation, e.g. adding wheat in a Corn-Bean rotation
2. Select shorter season varieties, need to have breeders look at higher yielding shorter season varieties
3. Remember having a living root growing for 6 to 8 weeks before a killing frost does provide benefit
4. Figure out ways to interseed cover crops into growing crops



Photos 29 Oct 2003



Hairy vetch

good fall growth



**Hairy vetch planted into
corn July 17**

**Hairy vetch planted into
bean June 29**

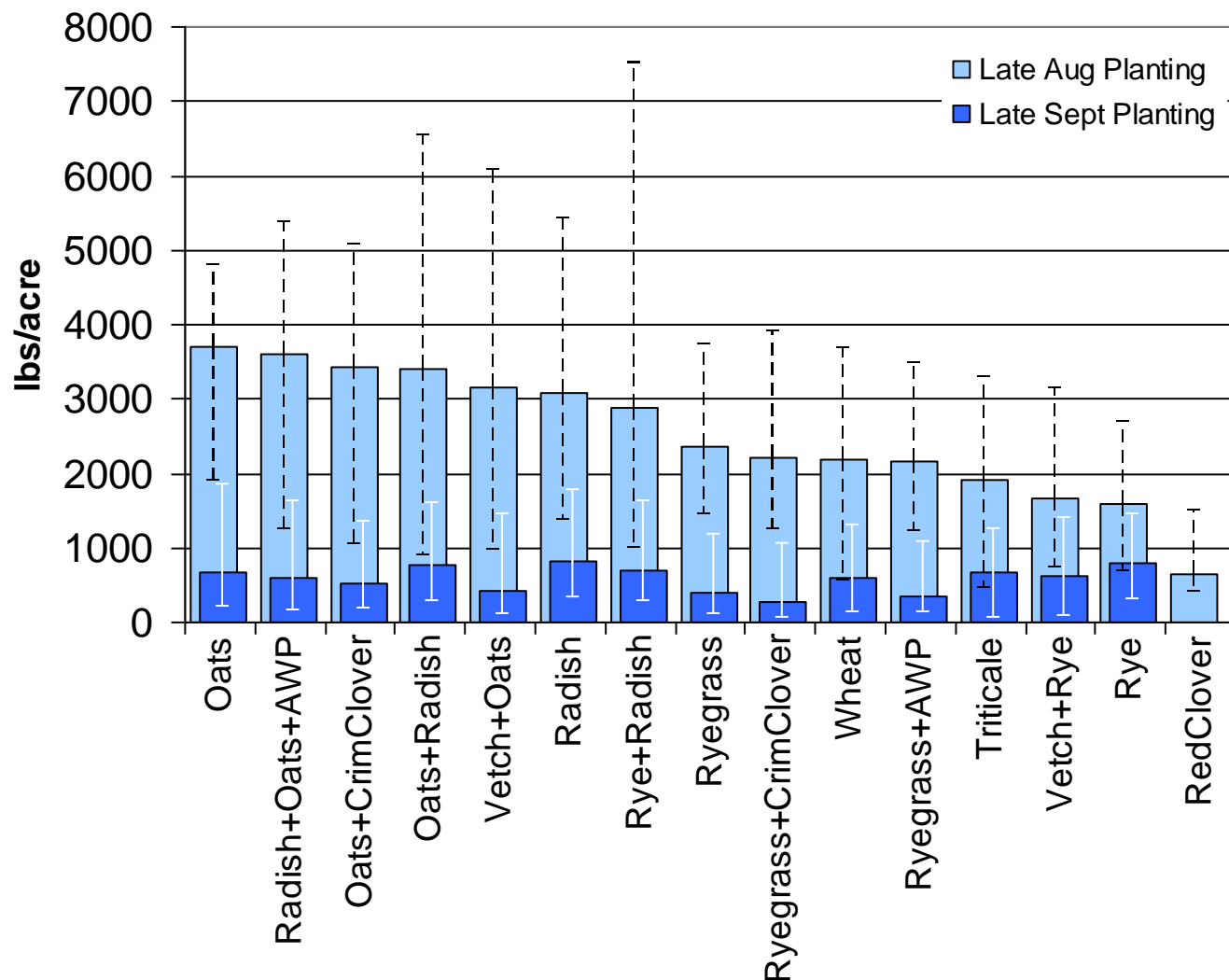
Photo shows the difference in growing of hairy vetch seeded at different times of the year

- **Early seeding allowed for more growing**, nothing earth shattering here.

Fall Biomass Data



Dry Matter of Both Planting Dates Measured in November



- Lose 50% to 80% of fall growth potential with a 1 month planting delay
- Later planting defers growth potential to spring
- Rye is the least impacted by a later planting date



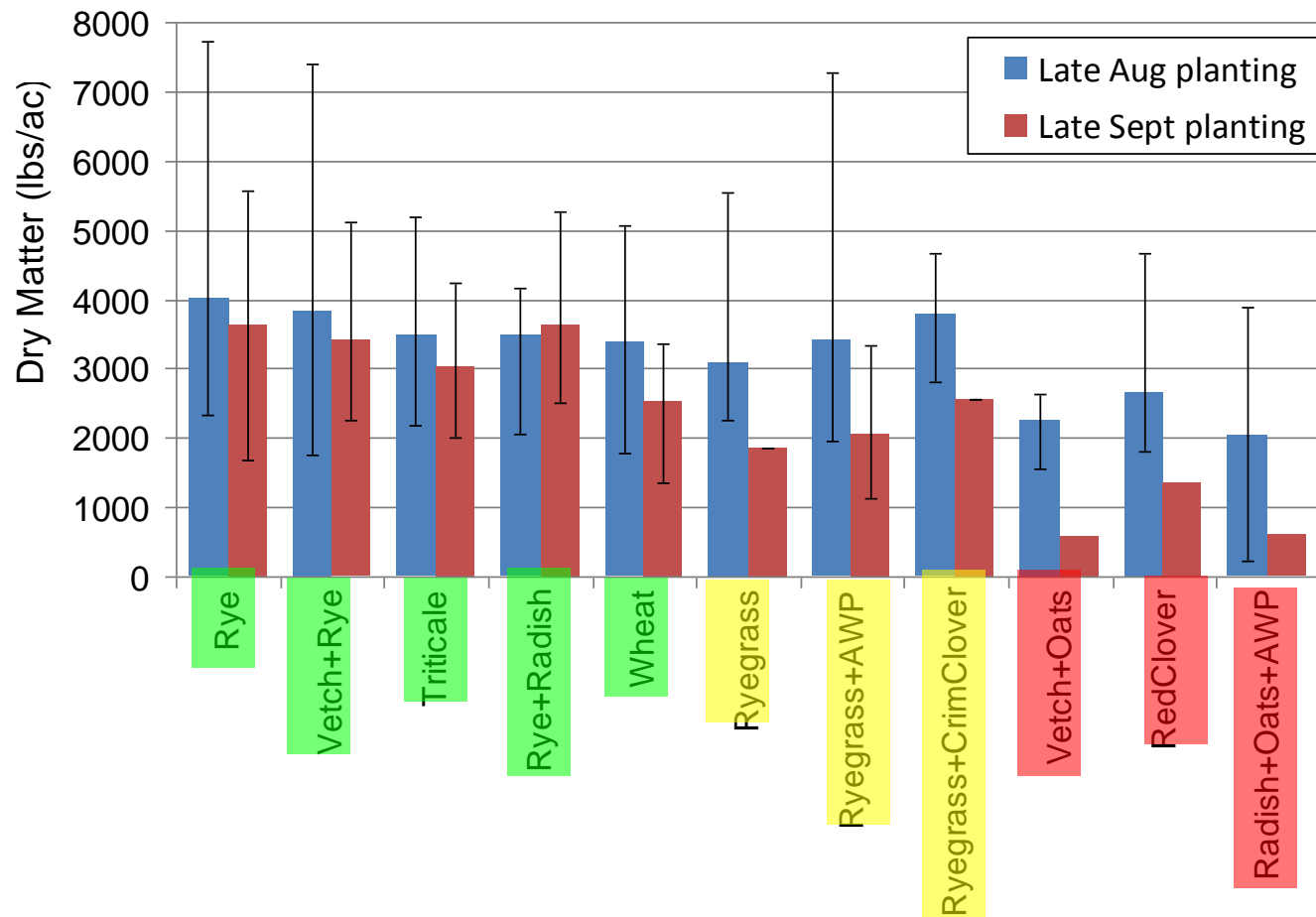
Penn State Study conducted in 2011 & 2012

- This group of cover crop mixes contained species that would freeze kill
- Early planting gained 50% to 80% more biomass than late planting

Spring Biomass Data



Cover Crop Biomass in April/May 2010



Rye and triticale containing mixtures were least impacted by a later planting date

Ryegrass containing mixtures were moderately impacted by a later planting date

Legumes w/ no spring growing companions were heavily impacted by a later planting date

Penn State Study conducted in 2011 & 2012

This table contains cover crops that will over winter

- Late seeding did not affect all cover crop species used, e.g. cereal grains not affected
- Legume containing mixes were impacted the most



Aerial Seeding

**How are farmers
getting it done?**



Advantage

- Seed most anytime
- Not affected by wet conditions
- Suited for small seed low rate cover crops

Disadvantages

- Limited on amount of seed they can carry
- Need to increase rates to compensate for poor seed to soil contact
- Cost

Penn State Cover Crop InterSeeder & Applicator



Penn State Cover Crop Interseeder & Applicator

- **With this system, cover crops are interseeded early in the season but provide minimal competition to the corn.**
- The interseeder is designed to be able to apply sidedress N fertilizer and a postemergent herbicide while seeding the cover crop,
- Eliminates the need for additional trips across the field and reducing the cost of seeding the cover crop.



Highboy air seeders

- Seed cover crops into corn & beans
- Uses a Hagie STS 12 with a Gandy Orbit Air seed box.
- Covers 90 feet / 36 rows and the hopper holds 65 bu.



“This is the last and greenest field I did. Still has a little time to go yet, but it should make some corn. Most other fields are brown with grain moisture, I'm guessing, in the low 20's. The ground is getting more light, so we'll see if that makes a difference.” This is the farmer's comment



Broadcast while defoliating cotton



Seeded a multi-species
cover crop mix

- Cereal rye
- Crimson clover
- Hairy Vetch



Broadcast seeding of cover crop as spray cotton defoliant using a multi-species cover crop mix.
Great stand.

Problem was farmer could spray more acres than he could broadcast, hopper not large enough.

Corn Chopper --cuts top out of mature corn



Here's a radical idea, farmer used a corn chopper (actually they are lawnmower blades) to cut the top off of mature corn (above the ear) while broadcasting cover crop seed. **Corn is drying down and waiting to be harvested.**

The key point to all of the slides being that once you convince farmers of the benefits of seeding their cover crop early they will figure out a way to make it happen.

Soil Health Principle 3

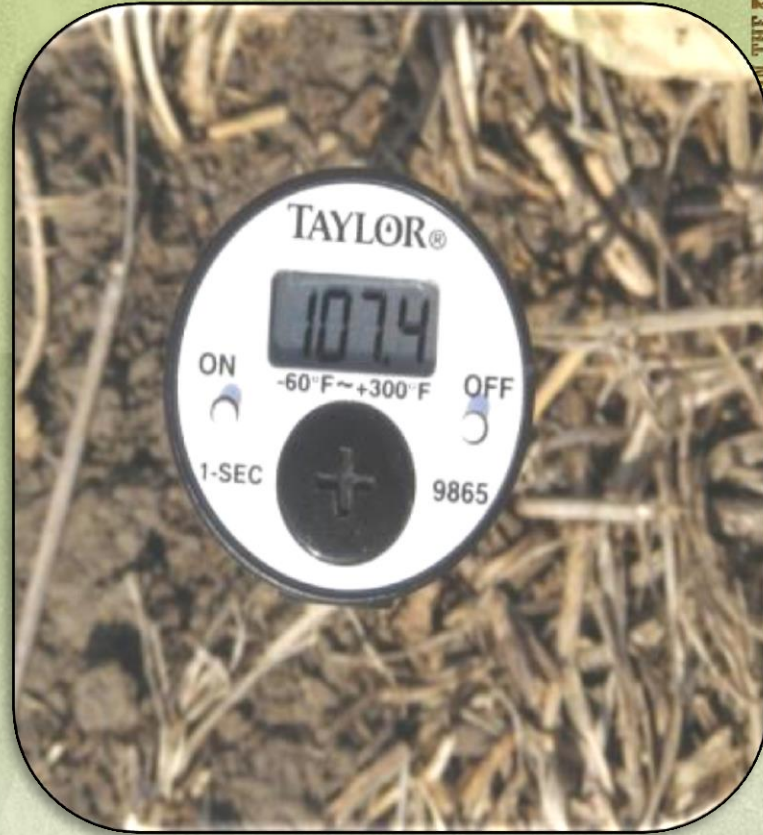
Keep it Covered as Much as Possible

Benefits:

- **Control Erosion**
- **Protect Soil Aggregates**
- **Suppresses Weeds**
- **Conserves Moisture**
- **Cools the Soil**
- **Provides Habitat for Soil Organisms**

- The benefits of keeping the soil covered have focused primarily on the erosion control side, we don't need to discuss this much, thousands of HEL conservation plans have been written based on this.
- Providing residue all year round does more than prevent erosion.
- **Cooler soils reduce evaporation and conserve moisture.**
- **Residue provides habitat for soil organisms.**

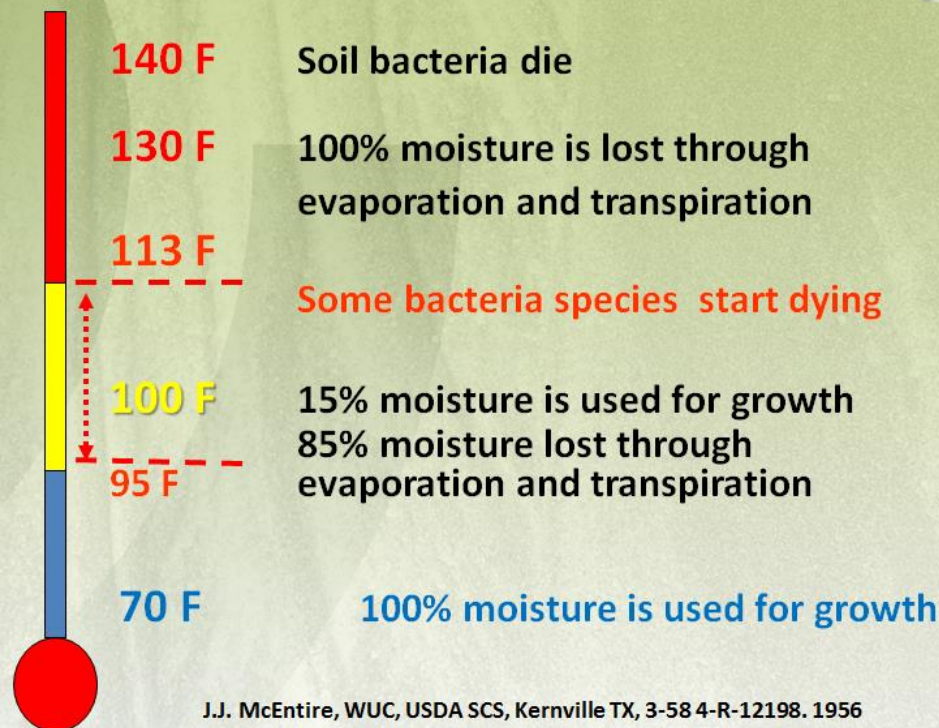
Soil Temperatures



- **Conserve moisture and reduce temperature.**
- **Crop yields are limited more often by hot and dry, not cool and wet soils.**

Notice the temperature difference between bare soil and soil with cover crops. Thermometers are placed 40 feet apart in two differently managed fields. **Soil temperatures are 20 degrees cooler where cover crop is shading the soil.**

When soil temperature reaches



- Soil temperatures are a way of determining the health of you cropland and pastures.
- By placing a temperature gauge on the surface can show you what kind of **micro climate** you have created.
- Soil temperatures can exceed ambient air temperatures by 10 to 20 degrees.
- Plant use of moisture is directly linked to soil temperature:
 - At 70 F soil temps 100% of the moisture is used for growth, none is loss.
 - At 100 F you lose 85% of your moisture through evaporation-transpiration.
 - At 113 F 100% of soil moisture is lost through evaporation-transportation, no plant growth is occurring.
 - Plants natural reaction to hot temperatures is to evaporate soil moisture through there system to cool itself.
 - Protein cooks at 120 degrees F. Thus the plant will avoid being cooked by using all the moisture you have caught in the soil for Air Conditioning.
 - At 130 F soil organisms start to die.
 - So it is important to manage for cool soil conditions. This is the biggest loser of soil moisture. Hot ground means you have created a drought even during moist years.

What happens to residue?

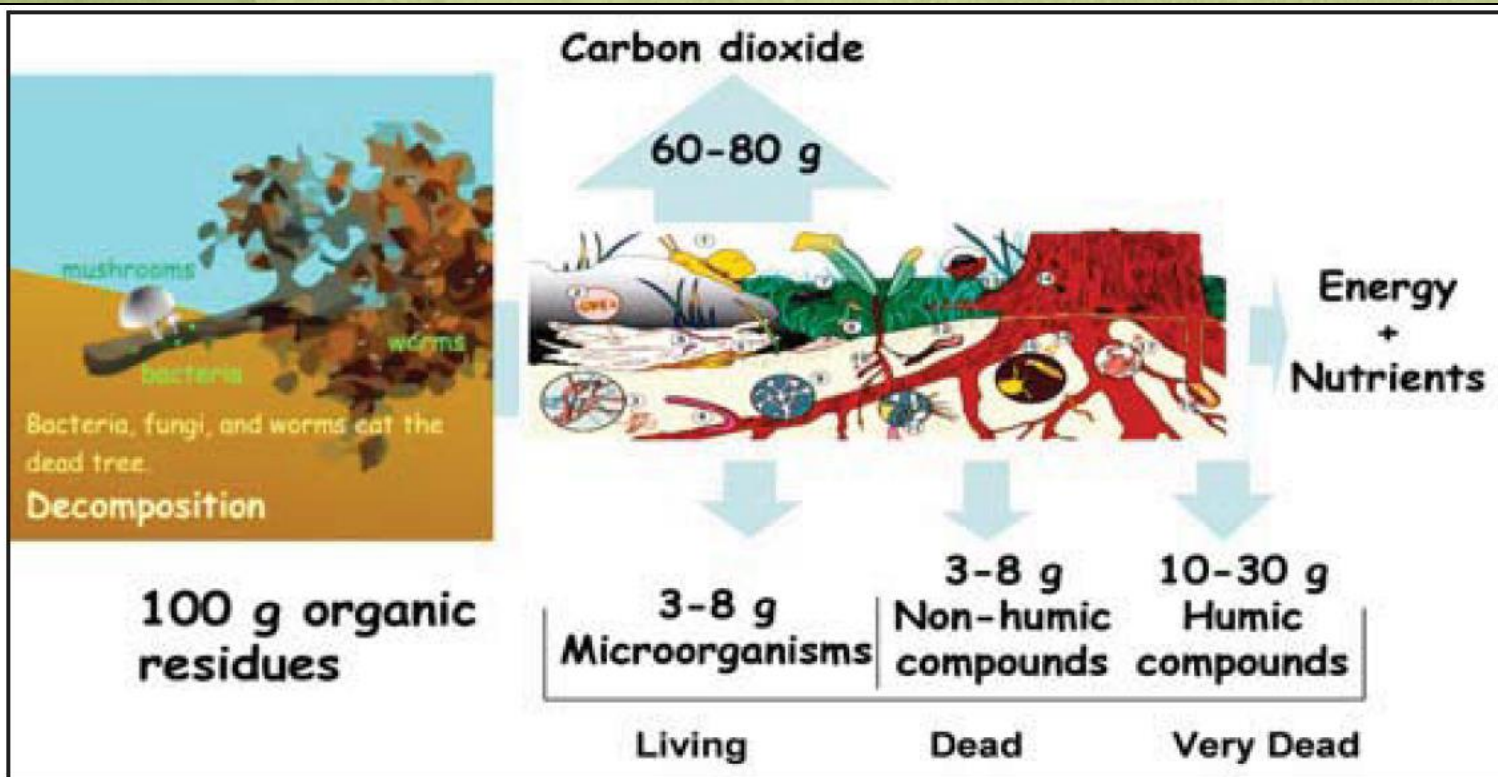


Diagram by Dr. Rafiq Islam

- One hundred grams (g) or 100 pounds (lbs) of dead plant material yields about 60-80 g (lbs) of carbon dioxide, which is released into the atmosphere.
 - The remaining 20-40 g (lbs) of energy and nutrients is decomposed and turned into
 - 3-8 g (lbs) of microorganisms (the living)
 - 3-8 g (lbs) of non-humic compounds (the dead)
 - 10-30 g (lbs) of humus (the very dead matter, resistant to decomposition).
- The molecular structure of SOM is mainly carbon and oxygen with some hydrogen and nitrogen and small amounts of phosphorus and sulfur.
- Soil organic matter is a by-product of the carbon and nitrogen cycles.

Soil Organic Matter Nutrient Bank Account.



- **1.0% OM = 20,000 #**
 - 10,000 # Carbon (5 ton) @ \$4/ton = \$20
 - 1,000 # Nitrogen @ \$.50/# = \$500
 - 100 # Phosphorous @ \$.70/# = \$70
 - 100# Potassium @ \$.40/# = \$40
 - 100 lbs of Sulfur @ \$.50/# = \$ 50
 - Total **\$680**
- **Mineralization Rate = 2-3% from Organic N to Inorganic N.**
- **Resulting in 20 to 30 lbs of useable N per acre.**

This is self explanatory, it shows the potential nutrients available in the SOM that can be tapped as soil health is improved and microbe activities is accelerated.

Soil Organic Matter & Available Water Capacity

Percent SOM	Sand	Silt Loam	Silty Clay Loam
1	1.0	1.9	1.4
2	1.4	2.4	1.8
3	1.7	2.9	2.2
4	2.1	3.5	2.6
5	2.5	4.0	3.0

Inches of Water/One Foot of Soil
1 acre inch = 27,150 gallons of water

Berman Hudson
 Journal Soil and Water Conservation 49(2) 189 194 189-
 March April 1994 –
 Summarized by:
 Dr. Mark Liebig, ARS, Mandan, ND
 Hal Weiser, Soil Scientist, NRCS, Bismarck, ND

This is AVAILABLE water not simply water being held in the soil profile.

What does it mean on a practical side:

- The average increase in available water is .5"
- This amounts to an extra 13,575 gallons of available water
- Corn water use at it maximum growth rate in the summer uses .25" to .3" of water or 6,000 to 8,000 gallons
- This amount of extra water would be equivalent to 2 irrigation events to meet corn needs
- This would amount to decreasing the number of irrigation events needed or extending the time between irrigation events
- **It would also mean extra days between rainfall events before non-irrigated crops begin to stress**

Soil Organic Matter Facts

- Soil organic matter (SOM) is <6% of soil by weight but controls >90% of the function
- Density of SOM: .6 g/cm³ Density of Soil: 1.45 g/cm³
- SOM has less density than soil so it has more space for air and water storage
- SOM is negatively charged, but binds both cations and anions
- Every Pound SOM holds 18-20# of Water!
- As soil organic matter increases from 1% to 3%, the available water holding capacity of the soil doubles (Hudson, 1994)
- Soils stockpile 1500 gigatons of carbon in SOM, more than Earth's atmosphere and all the plants combined (Dance, 2008)
- The majority of the SOM is present in the top 10 cm of soil



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